

UNITED STATES PATENT APPLICATION
FOR
TAPERED ELECTRODE IN AN ACOUSTIC RESONATOR

Inventors: Eyal Ginsburg
Li-Peng Wang
Alexander Talalyevsky
Eyal Bar-Sadeh
Doron Rubin

Prepared By:
BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP
12400 Wilshire Boulevard
Seventh Floor
Los Angeles, California 90025-1026
(206) 292-8600

Attorney Docket No.: 42P16637

"Express Mail" mailing label number: EV320119078US

Date of Deposit: June 27, 2003

I hereby certify that I am causing this paper or fee to be deposited with the United States Postal Service "Express Mail Post Office to Addressee" service on the date indicated above and that this paper or fee has been addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450

Dominique Valentino

(Typed or printed name of person mailing paper or fee)

Dominique Valentino

(Signature of person mailing paper or fee)

6-27-03

(Date signed)

TAPERED ELECTRODE IN AN ACOUSTIC RESONATOR

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention relates generally to acoustic resonators and, more specifically, the present invention relates to a method and apparatus for a tapered electrode in an acoustic resonator device.

Background Information

10 Acoustic resonators are often used as filters in wireless communication devices. Common types of acoustic resonators include Semiconductor Bulk Acoustic Resonators (SBAR) and Film Bulk Acoustic Resonators (FBAR). An FBAR includes a thin film of piezoelectric (PZ) material positioned between two conductive electrodes. Generally, an air cavity is formed below the bottom electrode.

15 Aluminum Nitride (AlN) and Zinc Oxide (ZnO) are often used as piezoelectric material.

20 When an electrical signal, such as a Radio Frequency (RF) signal, is applied across the FBAR, the PZ layer expands and contracts, creating a vibration. This vibration creates a mechanical energy (resonance). The fundamental resonance is observed when the thickness of the PZ layer is equivalent to half the wavelength of the input signal.

 When multiple FBAR resonators are combined, they can be used to produce a passband filter or a stopband filter. An FBAR can be used as a filter since it will function as an electronic resonator when allowed to operate at its mechanical

resonant frequency. FBARs resonate at GHz frequencies and are sized at the micron level, thus making them ideal for wireless communication devices.

A prior art FBAR is shown in Figure 1. A dielectric layer 12 is formed over substrate 10. Positioned on top of dielectric 12 is a bottom electrode 14. Bottom electrode 14 has a nearly vertical edge making an abrupt end 15. Formed on top of the bottom electrode 14 is piezoelectric layer 16. Positioned on the piezoelectric layer 16 is a top electrode 18. A cavity 20 is formed in substrate 10 and dielectric 12, the top of the cavity 20 defined by bottom electrode 14.

AlN is a well-known ceramic piezoelectric material. When the AlN layer is deposited, it follows the terrain of the under layer and has a tendency to crack when layered over sharp topography. Even small steps of 500 Angstroms in the under surface may cause the AlN to crack. Referring again to Figure 1, a crack 22 has developed due to the abrupt end 15 of the bottom electrode 14. Cracks in the PZ layer decrease device yield and thus raise the costs of FBAR production.

Also, an under layer with sharp topography affects the crystal orientation of AlN. In Figure 1, the abrupt edge 15 has caused disorientation in grains 24 of the AlN layer. If the AlN grains are not highly oriented, then the FBAR will experience acoustic losses.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the accompanying figures.

Figure 1 is a cross-sectional view diagram illustrating a prior art FBAR.

5 Figure 2 is a cross-sectional view diagram illustrating one embodiment of a tapered electrode of an acoustic resonator in accordance with the teachings of the present invention.

10 Figure 3 is a bottom view diagram illustrating one embodiment of a tapered electrode of an acoustic resonator in accordance with the teachings of the present invention.

Figures 4A and 4B are cross-sectional diagrams illustrating one embodiment of constructing a tapered electrode in accordance with the teachings of the present invention.

15 Figure 5 is a diagram illustrating one embodiment of a wireless device in accordance with the teachings of the present invention.

DETAILED DESCRIPTION

Methods and apparatuses to provide a tapered electrode in an acoustic resonator are disclosed. In the following description numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will
5 be apparent, however, to one having ordinary skill in the art that the specific detail need not be employed to practice the present invention. In other instances, well-known materials or methods have not been described in detail in order to avoid obscuring the present invention.

Reference throughout this specification to “one embodiment” or “an
10 embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures
15 or characteristics may be combined in any suitable manner in one or more embodiments. In addition, it is appreciated that the figures provided herewith are for explanation purposes to persons ordinarily skilled in the art and that the drawings are not necessarily drawn to scale.

Referring to Figure 2, an acoustic resonator 200 according to one
20 embodiment of the present invention is shown. The acoustic resonator 200 includes, but is not limited to, a Film Bulk Acoustic Resonator (FBAR), a Surface Acoustic Wave (SAW), or the like.

Formed on top of a substrate 202 is a dielectric layer 204. Substrate 202 includes, but is not limited to, Silicon (Si), Magnesium Oxide (MgO), Gallium Arsenic (GaAs), or the like. The dielectric layer 204 includes, but is not limited to, Silicon Dioxide (SiO₂), Silicon Nitride (SiN_x), or the like. In one embodiment, a portion of
5 substrate layer 202 and dielectric layer 204 is removed to form a cavity 214. The cavity 214 may be formed by dry etching or wet etching and is created to decrease insertion loss of the acoustic resonator 200.

Positioned on top of the dielectric layer 204 is a bottom electrode 206 having a tapered end 210. Formed over the bottom electrode 206 is a piezoelectric (PZ)
10 layer 208. PZ layer 208 includes, but is not limited to, Aluminum Nitride (AlN), Zinc Oxide (ZnO), lead titanate zirconate (PZT), lead scandium tantalum oxide, bismuth sodium titanium oxide, or the like. In an acoustic resonator using AlN, the AlN can be deposited by a Physical Vapour Deposition (PVD) reactive sputtering technique. A top electrode 212 is positioned on the PZ layer 208. Thus, at least a portion of PZ
15 layer 208 is sandwiched between bottom electrode 206 and top electrode 212. The electrodes 206 and 212 connect electrical signals to the acoustic resonator 200. Bottom electrode 206 and top electrode 212 each include, but are not limited to, aluminum (Al), chromium (Cr), gold (Au), platinum (Pt), molybdenum (Mo), or the like, or any combination thereof.

20 As described above, bottom electrode 206 includes tapered end 210. The bottom side of bottom electrode 206 remains generally flat. The upper side of bottom electrode 206 gently slopes downward to create the tapered end 210. In one embodiment, an angle 220 of the tapered end 210 may be between approximately

five (5) degrees and thirty (30) degrees. The angle 220 of the tapered end 210 may vary along the length of the bottom electrode 206 and does not have to be the same number of degrees along the entire length of the tapered end 210. The slope of the tapered end 210 is adjusted with respect to the thickness and stress of the PZ layer

5 208. In one embodiment, the tapered end 210 forms angle 220 of 6.7 degrees. The thickness of the PZ layer is designed to achieve the desired resonator frequency.

Generally, the higher the resonator frequency, the less the thickness of the PZ layer.

In one embodiment, the height of the bottom electrode 206 is approximately 53 nanometers (nm) at its thickest point and the height of a PZ layer of AlN is

10 approximately 2,657 nm. It will be understood that the bottom electrode 206 is not limited to the representation as shown in Figure 2. The tapered end 210 is formed in order to prevent cracking and discontinuity in the PZ layer as well as to maintain highly oriented grains in the PZ material.

Figure 3 is a bottom view diagram of an acoustic resonator 300 in accordance
15 with one embodiment of the present invention. The acoustic resonator 300 includes a bottom electrode 306 and a PZ layer 308. Bottom electrode 306 and PZ layer 308 are similar to bottom electrode 206 and PZ layer 208 as described above in conjunction with Figure 2. In one embodiment, the material used for PZ layer 308 is AlN. A substrate layer and a dielectric layer are not shown in Figure 3 for clarity. PZ
20 layer 308 fills the complete parameter of Figure 3 and a portion of the PZ layer 308 is hidden from view by bottom electrode 306.

Bottom electrode 306 includes a tapered end 302. The tapered end 302 is shown generally as the broken line around a portion of the parameter of bottom

electrode 306. Bottom electrode 306 is thickest at its center and becomes thinner while moving toward its outer edges. This mild topography of the bottom electrode 306 will prevent cracking and cause highly orientated grains in PZ layer 308. In one embodiment, bottom electrode 306 slopes across its entire surface so that the

5 thickest portion is in the center of the bottom electrode 306 and the thinnest portions are at the outer edges. In another embodiment, the bottom electrode is of uniform thickness except at the tapered end 302 where the bottom electrode 306 begins to slope downward.

Using a tapered electrode in an acoustic resonator offers several advantages.

10 When a PZ layer is formed, it follows the topography of the layer it is formed upon. Eliminating cracks and discontinuity in the PZ layer increases the die yield of acoustic resonators and reduces the costs of production. The tapered electrode has resulted in die yield improvement of 15-80% based on PZ layer cracking. Also, providing a mild topography below a layer of piezoelectric material decreases the

15 acoustic losses because the grains of the PZ material will be highly oriented in the same direction.

Figures 4A – 4B illustrate one embodiment of a method to fabricate a tapered electrode. Figure 4A shows acoustic resonator fabrication prior to the etching phase. A metal layer 404 has been applied to a dielectric layer 402. A photoresist

20 layer 406 has been applied to metal layer 404. In one embodiment, the metal layer 404 is aluminum. A mask (not shown) has been placed on photoresist layer 406 and the photoresist layer 406 has been exposed and the exposed photoresist removed by developer. At this point, the etching process may begin.

In Figure 4B, an etching process has been performed to create a tapered electrode 405 from metal layer 404. In one embodiment, the tapered electrode 405 is created through a dry etching technique. In another embodiment, a standard developer solution is used in a wet etching process to gently etch the tapered electrode 405. The developer initially defines the exposed and unexposed areas of the photoresist layer 406. As time passes, the developer starts to consume the photoresist layer, particularly on the line edges. Continuing to add developer creates a tapered electrode 405 and leaves dielectric 402 intact. The wet etch is isotropic such that there is a different etch rate between the metal layer 404 and the photoresist layer 406. The developer etches unexposed positive photoresist of the photoresist layer 406 faster than the metal layer 404. The photoresist layer 406 is reduced isotropically with time, thus, part of the metal layer 404, mostly at the edges, is also affected by the developer. The remaining photoresist layer 406 is then stripped by methods well known in the art. An acoustic resonator is then fabricated that includes tapered electrode 405.

Figure 5 shows a wireless device 500 according to one embodiment of the present invention. The wireless device 500 includes, but is not limited to, a wireless phone, a wireless computer network connection, a personal digital assistant (PDA) with a wireless connection, or the like. The wireless device 500 includes a FBAR filter 502 coupled to a transmitter 504. The FBAR filter 502 includes at least one FBAR device with a tapered electrode as described above. The transmitter 504 is coupled to an antenna 506. The FBAR filter 502 receives an input signal to be transmitted by the wireless device 500. The FBAR filter 502 filters the input signal

and outputs an output signal to transmitter 504. The transmitter 504 amplifies the output signal and then sends the output signal to the antennae 506.

In the foregoing detailed description, the method and apparatus of the present invention have been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the present invention. The present specification and figures are accordingly to be regarded as illustrative rather than restrictive.